NRL Memorandum Report 2141

ARPA Coupling Program on Stress-Corrosion Cracking (Fourteenth Quarterly Report)

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Physical Metallurgy Branch
Metallurgy Division

Sponsored by

Advanced Research Projects Agency
ARPA Order No. 878

May 1970

NAVAL RESEARCH LABORATORY
Washington, D.C.

45

Quarterly Report Series on the
ARPA COUPLING PROGRAM ON STRESS-CORROSION CRACKING

First Quarterly Report, NRL Memorandum Report 1739 (Dec 1966)

Second Quarterly Report, NRL Memorandum Report 1775 (Apr 1967)

Third Quarterly Report, NRL Memorandum Report 1812 (Aug 1967)

Fourth Quarterly Report, NRL Memorandum Report 1834 (Nov 1967)

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ABSTRACT

This report contains a compilation of abstracts from journal articles, recent reports, and talks generated under the ARPA Coupling Program on Stress-Corrosion Cracking, ARPA Order 878. The abstracts are from work done at The Boeing Company, Carnegie-Mellon University, Lehigh University, and the Naval Research Laboratory. Selected abstracts of articles from outside the ARPA Program in the field of stress-corrosion cracking are also included as well as a Diary of Events section.

STATUS

This report is the final quarterly report on the Coupling Program. The final technical report will be issued after 30 June 1970.

AUTHORIZATION

NRL Problems 60M04-08
61M04-08
63M04-08A
ARPA Order No. 878

ARPA Coupling Program on Stress-Corrosion Cracking
(Fourteenth Quarterly Report)

INTRODUCTION

The problem area of stress-corrosion cracking (SCC) in structural materials leading to failures in engineering structures has been of continuing concern to the Department of Defense and to other users of structural materials. Although considerable progress had been made in the field of corrosion, insufficient information was available to reach reliable conclusions on the phenomena of SCC and on the mechanisms involved. Without the development of reliable mechanism(s) and understanding of the factors involved in SCC phenomena, development and application of high strength alloys for reliable service in various environments can proceed only empirically.

To bridge the gap in fundamental knowledge needed to understand and to cope with the problem of SCC and to apply this knowledge to obtaining improvement of SCC resistance in existing and newly developed high strength alloys, the Advanced Research Projects Agency (ARPA) of DoD established a project on SCC under ARPA Order No. 878. This project, a broadly based interdisciplinary experiment, involves a coupling program between academic, industrial, and Government laboratory participants. The technological goal is to learn how to improve high strength structural alloys with respect to their resistance to SCC under various environmental and stress conditions, or at least learn how to "live with" the alloys which we have not been able to improve sufficiently.

Academic disciplines needed in the attack on the SCC problem area were considered to include: modern physical metallurgy, surface chemistry and electrochemistry, physics of surfaces, continuum mechanics as applied to fracture, advanced techniques of analysis, and development of environment-metal reaction theory. The industrial participant affords a means of amplifying a Government laboratory's in-house capability without an increase in in-house staff. The Government laboratory's role was to exercise overall project direction, to provide direction guidance as to DoD needs, and to conduct basic and applied research.

The academic participants and their principal discipline areas include the following:

a. Carnegie-Mellon University -- Advanced physical metallurgy and electrochemistry.

b. Georgia Institute of Technology -- Surface physics and physical metallurgy.

c. Lehigh University -- Surface chemistry, metallurgy, and fracture mechanics.

d. American University -- Solution chemistry and electrochemical effects (in aluminum).

e. University of Florida -- Electrochemistry, particularly in conducting Pourbaix-type analyses for alloy systems.

The Boeing Company, the industrial partner, develops standard test methods and characterizes SCC properties of advanced high strength alloys; provides technical guidance in areas of special competence; and conducts a limited amount of basic research in related areas.

The Naval Research Laboratory is the Government laboratory participant. Its research and discipline areas are: physical metallurgy, electrochemistry, surface chemistry, solution chemistry, surface physics, and fracture mechanics.

In addition, NRL identifies relevant military hardware needs in the area of SCC.

The technical reporting system includes the following:

Detailed technical progress from each project participant is published twice yearly in the quarterly report series. The technical progress report is organized into three main categories: Titanium, Steel, Aluminum. Each main category is further divided according to material classification and to research discipline. The individual progress reports are sent to and edited by category editors who in turn submit the edited progress reports to NRL for assembly into the quarterly report and publication as an NRL report. The remaining two quarterly reports contain 1) abstracts of newly published reports of project sponsored research, 2) a chronological list of titles of all ARPA-generated reports, and 3) selected abstracts of reports and journal articles of work related to SCC outside the ARPA project. A final item is a diary of events section.

This report is the final report in the series. The final Technical Report of the Program is in preparation.

A. ABSTRACTS OF ARPA-GENERATED MANUSCRIPTS, REPORTS, AND TALKS

The Boeing Company

1. J. A. Feeney and M. J. Blackburn, "Effect of Microstructure on the Strength, Toughness, and Stress-Corrosion Cracking Susceptibility of a Metastable Beta Titanium Alloy (Ti-11.5Mo-6Zr-4.5Sn)," Boeing Document D6-24472, February 1970

This paper describes the influence of microstructure on the mechanical properties of the alloy Ti-11.5Mo-6Zr-4.5Sn. The phase transformations are similar to those that occur in binary Ti-Mo alloys containing 10% to 12% Mo. Thus the β-phase can be retained by quenching from above 1400° F. The β-phase deforms in a complex manner, including mechanical twinning, and is characterized by low strength, high ductility, and high toughness. The ω-phase, which also forms on quenching, is stable at temperatures up to 800° F. Yield strengths of up to 220 ksi have been measured in (β + ω) structures, the strength level being dependent on the size and volume fraction of the ω-phase. In contrast, fracture toughness reaches a minimum value of ~ 20 ksi$\sqrt{\text{in.}}$ when the ω-particle size ≈ 100 Å. (β + α) structures show good combinations of yield strength and fracture toughness. Unfortunately, the best combinations are susceptible to stress-corrosion cracking in aqueous solutions containing halide ions.

2. M. J. Blackburn and J. A. Feeney, "Stress-Induced Transformations in Ti-Mo Alloys," Boeing Document D6-25210, February 1970

The deformation characteristics of the metastable beta alloy Ti-11.5Mo-6Zr-4.5Sn (Beta III) have been studied. In the range -196° to +150° C, Beta III deforms primarily by mechanical twinning and to a lesser extent by slip and stress-induced orthorhombic martensite formation. The twin system is {332}<113> and not the {112}<111> system normally operating in body-centered cubic materials.

3. C. S. Carter, D. G. Farwick, A. M. Ross and J. M. Uchida, "Stress-Corrosion Properties of High-Strength, Precipitation-Hardening Stainless Steels in 3.5% Aqueous Sodium Chloride," Boeing Document D6-25219, February 1970

The plane-strain fracture toughness K_{Ic} and stress-corrosion threshold K_{Iscc} have been determined for the following high-strength, precipitation-hardening steels: 17-7PH (RH 950, TH 1050), PH 15-7Mo (RH 950, TH 1050), AM 355 (SCT 850, SCT 1000), AM 362 (H 900, H 1000), AM 364 (H 850, H 950), 17-4 PH (H 900, H 1000), 15-5 PH airmelted and vacuum melted (H 900, H 1000), PH 13-8Mo (H 950), and Custom 455 (H 950). Correlations of K_{Iscc} with service performance, smooth-specimen test data, and chemical composition are discussed.

4. M. V. Hyatt and W. E. Quist, "Effect of Aging at 250° F on Stress Corrosion Crack Growth Rates in 2024-T351 Aluminum," Boeing Document D6-25218, March 1970

The short transverse stress-corrosion resistance of 1.0 inch thick 2024-T351 plate material after exposure at 250° F has been measured using precracked double cantilever beam (DCB) specimens. The susceptibility of the material was assessed by measuring stress-corrosion crack growth rates as a function of the plane strain stress intensity K in specimens periodically wetted by a 3.5% NaCl solution. The results showed that at K_I levels of 13-15 ksi$\sqrt{\text{in}}$. growth rates began to increase within the first two hours of exposure and continued to increase until approximately 100 hours of exposure. At K_I levels of 25-35 ksi$\sqrt{\text{in}}$., increases in stress-corrosion sensitivity were not apparent until after 2 hours of exposure but increased to a maximum in only 15 hours. The maximum crack growth rate difference noted between unexposed and exposed specimens was approximately 60%.

5. D. Webster, "Effect of Grain Refinement on the Microstructure and Mechanical Properties of 4340M," Boeing Document D6-25220, April 1970

A new grain refinement technique involving grain boundary pinning by deformation voids has been investigated in 4340M steel. Significant grain refinement is observed in deformed specimens at all temperatures between Ac_1 and 50° F above Ac_3. In a narrow temperature region just above Ac_3, grain refinement produces an increase in strength and toughness but no increase in stress-corrosion threshold. It is concluded that to take full advantage of the new grain refinement process, compositional modifications of 4340M-type steels are required.

6. M. V. Hyatt and H. W. Schimmelbusch, "Development of a High-Strength, Stress-Corrosion Resistant Aluminum Alloy for Use in Thick Sections," Boeing Document D6-60122, March 1970

Several heats of a Boeing-recommended alloy (alloy 21) were cast by Reynolds and fabricated by Reynolds and Wyman-Gordon into die forgings, hand forgings, plate, and extrusions. All the wrought products were forwarded to Boeing for heat treatment of evaluation of mechanical, fracture, fatigue, and stress-corrosion properties.

Heat-treatment studies were performed on specimens of from 3-in.-thick plate of the new alloy. The degree of overaging required to achieve a 25 ksi smooth-specimen threshold stress was determined using stress-corrosion crack growth rate data from precracked double cantilever beam specimens. Based on these data, a T6 + 35 hr at 325° F treatment was finally selected. Metallographic studies on failed and unfailed smooth stress-corrosion specimens verified that the selected heat treatment was adequate to meet the stress-corrosion goal.

The wrought products of alloy 21 were heat treated in Boeing production facilities according to the heat treatment selected. Mechanical, fracture, and stress-corrosion properties for die forgings of alloy 21 and several other forging alloys may be seen in the following table.

Alloy	Thickness (in.)	Minimum longitudinal properties		Longitudinal K_{Ic} range	Short-transverse-stress-corrosion threshold (ksi)	
		F_{tu} (ksi)	0.2% F_{ty} (ksi)	(ksi$\sqrt{in.}$)	3.5% NaCl alternate immersion	Industrial atmosphere
Alloy 21	6.75	69*	60*	30-38*	> 25*	> 25*
7049-T73	5.0	70	60	30-38*	45	[illegible]
X7080-T7	6.0	65	57	27-30	25	15
7075-T73	3.0	66	56	27-38	> 47	> 47
7075-T73	6.0	61	51	27-38	> 47	> 47
7175-T736	3.0 max	76	66	27-38	~ 35	?
7075-T6	3.0 max	75	65	25-32	7	14
7079-T6	6.0	72	62	25-32	7	6

* Estimated values

The mechanical properties of alloy 21 are comparable to those of 7049-T73. The fracture toughness of alloy 21 is as good as or better than that of the other alloys listed. The smooth-specimen short-transverse stress-corrosion threshold appears to be greater than 25 ksi. Test data also indicate that the smooth and notched axial (tension-tension) fatigue properties of alloy 21 are comparable to those of 7075-T6 and 7075T73.

<u>Carnegie-Mellon University</u>

1. A. J. Stavros and H. W. Paxton, "Stress-Corrosion Cracking Behavior of an 18% Ni Maraging Steel," Metals Research Laboratory Report, April 1970, Carnegie Institute of Technology, Carnegie-Mellon University

Stress-corrosion cracking of an 18% Ni maraging steel in aqueous solutions was studied using precracked cantilever beam specimens. By appropriate heat treatments, six different structures having the same yield strength were obtained. Although significantly different plane strain fracture toughness values (K_{Ic}) resulted, it was found that the threshold plane strain stress intensity (K_{Iscc}) was the same for all structures. K_{Iscc} had the same value in 3% NaCl at various pH values, in IN H_2SO_4, and in distilled water. Specimens tested in 3% NaCl under both anodic and cathodic applied potentials also exhibited this same K_{Iscc} value. Fractographic inspection of the crack surfaces revealed no apparent differences due to changes in solution, pH, or applied potential. The crack path was intergranular in all cases. However, specimens austenitized at 1500° F exhibited crack branching, whereas in specimens austenitized at much higher temperatures branching no longer occurred. Aging time and temperature seemed to change only the time to failure. The mechanism most consistent with all observations appears to be hydrogen cracking.

2. Jei Y. Choi, "Diffusion of Hydrogen in Iron," Metallurgical Transactions <u>1</u>, April 1970, pp. 911-919

A mass spectrometer was used to study hydrogen diffusion and trapping phenomena in fully-annealed and slightly cold-worked pure iron specimens which were in contact with distilled water or dilute acidic Buffer solutions. In the case of fully-annealed iron and slightly cold-worked iron, hydrogen can diffuse into iron only when the iron contacts water directly. This diffusion

phenomenon of hydrogen increased markedly with temperature and was accelerated by abrasion and hydrogen ion concentration in dilute acid. Abrasion and hydrogen ions in a dilute acidic Buffer solution did not affect the diffusion coefficient of hydrogen, D, but increased the hydrogen concentration at the iron surface contacting water of Buffer solution, C_s. The permeability of hydrogen in fully-annealed iron in contact with distilled water and the diffusion coefficient of hydrogen in fully annealed and slightly cold-worked iron for the temperature range 10° to 100° C were measured. Trapping parameters in the slightly cold-worked iron were calculated.

3. Paul Fugassi and E. G. Haney, "Effect of Heavy Metal Ions on Susceptibility of AISI 4340 Foil to Stress Corrosion Cracking in Dilute Aqueous Hydrochloric Acid Solutions," Corrosion 26:3, March 1970, pp. 118-120

The time required for the cracking of AISI 4340 steel foil in dilute aqueous hydrochloric acid solution, pH = 1.5, is greatly increased by the presence of small amounts of Cd^{++}, Sn^{++}, and Pb^{++} in concentrations as low as 10^{-4} molar. It is suggested that these heavy metals, whose sulfides have solubility products in the range, 10^{-29} to 10^{-26}, form sulfides more insoluble at pH 1.5 than can be formed by certain areas present on the surface of the foil. Sulfided areas on the surface of the foil are assumed to accelerate the absorption of hydrogen by the foil.

Lehigh University

1. M. M. P. Janssen, "Release of Compressive Intrinsic Stress in Ultraclean Thin Nickel Films as a Result of Adsorption of Gases," J. Appl. Phys. 41, 384, 1970

Intrinsic stresses in continuous thin nickel films, evaporated at better than 5×10^{-10} torr onto glass substrates, were investigated by ferro-magnetic resonance techniques. All films as prepared in UHV gave high resonance field values indicating compressive stresses in the range of -4 to -8×10^{-9} dyne/cm^2. The compressive stresses were attributed to surface free energy. Adsorption of H_2, H_2O, CO, O_2, N_2O, and air at low pressures released the compressive stress. Stress relief was less complete for H_2, H_2O, and CO than for the other three gases. N_2 showed no stress release activity.

2. K. Klier, A. C. Zettlemoyer, and H. Leidheiser, Jr. "Chemisorption of Carbon Monoxide on (110) and (100) Nickel Crystal Faces," J. Chem. Phys. 52, 1970, p. 589

Adsorption equilibria, adsorption rates, and exchange rates of carbon monoxide have been investigated on nickel single crystal faces of the (110) and (100) orientation using radiotracer techniques. On the clean annealed surfaces, carbon monoxide is uniformly bound, is mobile, and occupies an area of 9 $Å^2$ in the saturated layer. The surface equilibria and the kinetic phenomena are both quantitatively accounted for by a theory utilizing the Stockmayer potential and a cell approximation for describing the lateral interaction of the adsorbed molecules.

The ion-bombarded non-annealed surfaces are unstable and heterogeneous. The contaminated surfaces absorb only minute amounts of carbon monoxide. Thus chemisorption of CO provides a useful criterion for the degree of cleanliness of nickel surfaces.

3. E. Chornet, R. W. Coughlin, and H. Leidheiser, Jr., "Flash Desorption of Argon Imbedded within Iron, Nickel, and Titanium," J. Colloid and Interface Science

After bombardment of the metal wires by argon ions of 150, 575, and 1000 V, the efflux of argon from the metal surfaces was monitored using the flash desorption technique in which the wires were heated from 25° C to 850° C. Two different heating schedules were employed - the one about 4 sec duration, the other about 60 sec.

Prior to argon bombardment the wires were chemically polished and outgassed in vacuum until the residual pressure with the wire hot was less than 3 x 10^{-10} torr. The cleanliness of the surface was assessed by measuring its hydrogen adsorption capacity. More than 60 min. of ion bombardment were necessary to achieve reproducible results. The experimental data of pressure (or ion current in the residual gas analyzer) versus time show definite peaks for each of the metals; this behavior suggests that the argon atoms lodge within the lattices at specific sites of discrete energy. An attempt is made to estimate these energies and to interpret the diversity of peaks observed for each metal in terms of the number of unique interstitial positions within the lattice of that metal.

4. K. Klier, "Adsorption of Carbon Monoxide on Iron Using Radio Tracer Techniques," J. Colloid and Interface Science

An ultra-high vacuum Geiger counter was used for monitoring chemisorption of ^{14}C-labeled carbon monoxide on the surfaces of iron polycrystals and the (100) iron crystal face.

From the measurements of isotherms, isobars, and sticking coefficients on the surfaces of various preparations it appeared that: 1) oxygen contaminated surfaces did not adsorb carbon monoxide, 2) there was no detectable difference in the adsorption capacity towards CO between the annealed polycrystal and the annealed (100) crystal faces, 3) there was a substantial difference in adsorption capacity toward CO between the ion-bombarded non-annealed and the electron-bombarded annealed surfaces. The saturated value of CO adsorption on the non-annealed surfaces was found to be 6.5×10^{14} molecules/cm^2 and on the annealed surfaces, 3×10^{14} molecules/cm^2 at 10^{-5} torr.

5. Henry Leidheiser, Jr. and Elsie Kellerman, "Strain Electrometry Studies of Aluminum," Corrosion <u>26</u>:3. March 1970, pp. 99-104

The potential of aluminum wires immersed in an electrolyte was followed after abrupt straining of 1.5-12%. The maximum potential achieved after straining in 0.1M NaCl decreased with decrease in pH, and the rate of decay to the initial steady-state value was independent of pH over the range of 1.5-6.5. The presence of dissolved oxygen in the solution increased the rate of decay to the steady-state value. The different potential behavior of untreated wires, wires heated in boiling water, and anodized wires was attributed to different mechanical properties of the oxide. The strain electrometry curves were identical in solutions of NaCl, Na_2SO_4, soldium tartate, and $Na_2Cr_2O_7$ of equal ionic strength. The pertinence of the results to the behavior of aluminum exposed at the tip of a growing stress-corrosion crack is discussed.

Naval Research Laboratory

1. B. F. Brown, "Stress-Corrosion Cracking: A Perspective View of the Problem," NRL Report 7130, 16 June 1970

The introduction includes definitions of a number of terms relating to crack propagation caused by the conjoint action of stress and corrosion and related phenomena. This is followed by a brief historical review during the course of which it becomes evident that stress-corrosion cracking, far from being restricted to a few alloys, is a general phenomenon observed in most families of alloys if the composition, heat treatment, and environment are favorable. The role of fracture mechanics in conducting and interpreting stress-corrosion cracking tests is discussed, and the several classes of mechanisms which have been postulated to account for stress-corrosion cracking are enumerated. The most serious deficiency in stress-corrosion technology is the inability to predict those combinations of alloys and environments which will give rise to stress-corrosion cracking.

2. C. D. Beachem, J. A. Kies, and B. F. Brown, "A Constant K Specimen for Stress-Corrosion Cracking Testing," Materials Research & Standards

The double-torsion crack propagation specimen previously used for glass has been adapted for use in investigating stress-corrosion cracking velocities in metal plates and sheets. The specimen is simple and inexpensive and can be used either at constant deflection for experiments with decreasing K_I or at constant load in experiments with decreasing K_I or at constant load in experiments at constant K_I.

3. B. F. Brown, "On the Existence of a Threshold Stress for Corrosion Cracking in Titanium Alloys in Salt Water," Materials Research & Standards

The reason for the uncertainty over the question of a genuine threshold stress (or stress intensity) for propagation of a stress-corrosion crack is discussed. An experimental method is described from which electrochemical data afford a positive conclusion regarding the existence of such a threshold for titanium alloys. An experiment is described which confirms by an independent method the foregoing conclusion, and the significance of the conclusion is discussed.

B. CHRONOLOGICAL LIST OF ARPA-GENERATED REPORTS AND TALKS†

American University

1. R. E. Meyers, "The Role of Selected Ions in the Corrosion of Aluminum," M.S. Thesis, June 1969

2. A. A. Adams and R. T. Foley, "Chemical Effects in the Corrosion of Aluminum and Aluminum Alloys--A Bibliography," American University Report, Nov 1969

3. A. M. McKissick, Jr., "Anion Corrosion of High Strength Aluminum Alloys," M.S. Thesis, Dec 1969

4. R. T. Foley, "The Role of the Chloride Ion in Iron Corrosion," Corrosion 26:2, Feb 1970, pp. 58-70

5. A. M. McKissick, Jr., A. A. Adams, and R. T. Foley, "A Brief Communication on Synergistic Effects of Anions in the Corrosion of Aluminum Alloys," Manuscript, Mar 1970

6. S. E. Traubenberg and R. T. Foley, "The Influence of Chloride and Sulfate Ions on Corrosion of Iron in Sulfuric Acid," Manuscript , 1970

† An incomplete citation indicates a manuscript submitted but not yet published.

The Boeing Company

1. N. M. Lowry, O. R. Mulkey, J. M. Kuronen, and J. W. Bieber, "Method of Measuring Crack Propagation Rates in Brittle Materials," Boeing Document D6-60072, May 1967

2. H. R. Smith, D. E. Piper, and F. K. Downey, "A Study of Stress-Corrosion Cracking by Wedge-Force Loading," Boeing Document D6-19768, June 1967; Engineering Fracture Mechanics 1, 1968, p. 123

3. J. C. Williams, "Some Observations on the Stress-Corrosion Cracking of Three Commercial Titanium Alloys," Boeing Document D6-19553, Sept 1967; ASM Trans. Quar. 60:4, Dec 1967, p. 646

4. D. N. Fager and W. F. Spurr, "Some Characteristics of Aqueous Stress Corrosion in Titanium Alloys," Boeing Document D6-60083, Sept 1967; ASM Trans. Quar. 61:2, June 1968

5. A. K. Mukherjee, "Oxidation Behavior of Titanium - A Review," Boeing Document D6-23620, Sept 1967

6. A. K. Mukherjee, "The Possible Role of Hydrogen in Stress-Corrosion Cracking of Titanium Alloys," Boeing Document D6-23621, Sept 1967

7. C. S. Carter, "Crack Extension in Several High-Strength Steels Loaded in 3.5% Sodium Chloride Solution," Boeing Document D6-19770, Nov 1967

8. C. S. Carter, "Terminal Fracture of Titanium Alloys Containing Stress-Corrosion Cracks," Boeing Document D6-19771, May 1968

9. J. C. Williams, R. R. Boyer, M. J. Blackburn, "Influence of Microstructure on the Fracture Topography of Titanium Alloys," Boeing Document D6-23622, June 1968; ASTM STP No. 453 entitled "Electron Microfractography" (1969)

10. D. Webster, "A Process of Increasing the Strength and Toughness of AFC 77 by Grain Refinement," Boeing Document D6-23290, 1968

11. D. Webster, "Increasing the Toughness of AFC 77 by Control of Retained Austenite Content," Boeing Document D6-23449, 1968

12. R. E. Curtis, "Relationship Between Composition, Microstructure, and Stress-Corrosion Cracking in Titanium Alloys," Boeing Document D6-23716, Sept 1968

13. D. N. Fager, "Methanol Cracking of Titanium-8Al-1Mo-1V," Boeing Document D6-23717, Sept 1968

14. R. E. Curtis, R. R. Boyer, and J. C. Williams, "Relationship between Composition, Microstructure, and Stress Corrosion Cracking (in Salt Solution) in Titanium Alloys," Boeing Document D6-23716, Oct 1968; ASM Trans. Quar. 62:2, June 1969, pp. 457-469

15. D. Webster, "The Use of Deformation Voids to Refine the Austenite Grain Size and Improve the Mechanical Properties of AFC 77," Boeing Document D6-23870, Feb 1969; ASM Trans. Quar.

16. M. O. Speidel, "Interaction of Dislocations with Precipitates in High Strength Aluminum Alloys and Susceptibility to Stress Corrosion Cracking," Proceedings - Conference on Fundamental Aspects of Stress Corrosion Cracking, NACE Houston (1969) p. 561

17. C. S. Carter, "The Effect of Silicon on the Stress Corrosion Resistance of Low Alloy, High-Strength Steels," Boeing Document D6-23872, Mar 1969; Corrosion 25:10, Oct 1969, pp. 423-431

18. C. S. Carter, "Stress Corrosion Crack Branching in High-Strength Steels," Boeing Document D6-23871, Mar 1969; Engineering Fracture Mechanics

19. J. A. Feeney, J. C. McMillan, and R. P. Wei, "Environmental Fatigue Crack Propagation of Aluminum Alloys at Low Stress Intensity Levels," Boeing Document D6-60114, May 1969

20. M. J. Blackburn and J. C. Williams, "Metallurgical Aspects of the Stress Corrosion Cracking of Titanium Alloys," Proceedings - Conference on Fundamental Aspects of Stress Corrosion Cracking, NACE, Houston (1969) pp. 620-636

21. S. Mostovoy, H. R. Smith, R. G. Lingwall and E.J. Ripling, "A Note on Stress Corrosion Cracking Rates," submitted to Engineering Fracture Mechanics for publication in 1969

22. R. E. Curtis and P. T. Finden, "Titanium Alloy Development - Interim Report," Boeing Document D6-22997-1, June 1969

23. D. Webster, "The Stress Corrosion Resistance and Fatigue Crack Growth Rate of a High Strength Martensitic Stainless Steel, AFC 77," Boeing Document D6-23973, June 1969

24. M. V. Hyatt, "Use of Precracked Specimens in Stress Corrosion Testing of High-Strength Aluminum Alloys," Boeing Document D6-24466, Nov 1969

25. M. V. Hyatt, "Use of Precracked Specimens in Selecting Heat Treatments for Stress-Corrosion Resistance in High-Strength Aluminum Alloys," Boeing Document D6-24467, Nov 1969

26. M. V. Hyatt, "Effects of Residual Stresses on the Stress Corrosion Crack Growth Rates in Aluminum Alloys," Boeing Document D6-24469, Nov 1969

27. M. V. Hyatt, "The Effects of Specimen Geometry and Grain Structure on the Stress-Corrosion Cracking Behavior of Aluminum Alloys," Boeing Document D6-24470, Nov 1969

28. M. V. Hyatt, "The Effect of Quenching Rate on the Stress Corrosion Crack Growth Rates in 2024-T4 Aluminum," Boeing Document D6-24471, Nov 1969

29. D. Webster, "Stainless Steels Can Be Strong and Tough," Boeing Document D6-24379, 1969

30. D. Webster, "The Stress Corrosion Resistance and Fatigue Crack Growth Rate of a High Strength Martensitic Stainless Steel AFC 77," Boeing Document D6-23973, 1969

31. M. J. Blackburn and J. A. Feeney, "Stress-Induced Transformations in Ti-Mo Alloys," Boeing Document D6-25210, Feb 1970

32. J. A. Feeney and M. J. Blackburn, "Effect of Microstructure on the Strength, Toughness, and Stress-Corrosion Susceptibility of a Metastable Beta Titanium Alloy (Ti-11.5Mo-6Zr-4.5Sn)," Boeing Document D6-24472, Feb 1970

33. C. S. Carter, D. G. Farwick, A. M. Ross and J. M. Uchida, "Stress-Corrosion Properties of High-Strength, Precipitation-Hardening Stainless Steels in 3.5% Aqueous Sodium Chloride," Boeing Document D6-25219, Feb 1970

34. M. V. Hyatt and W. E. Quist, "Effect of Aging at 250°F on Stress Corrosion Crack Growth Rates in 2024-T351 Aluminum," Boeing Document D6-25218, Mar 1970

35. M. V. Hyatt and H. W. Schimmelbusch,"Development of a High-Strength,Stress-Corrosion Resistant Aluminum Alloy for Use in Thick Sections," Boeing Document D6-60122, Mar 1970

36. D. Webster, "Effect of Grain Refinement on the Microstructure and Mechanical Properties of 4340M," Boeing Document D6-25220, Apr 1970

37. R. R. Boyer, "The Effect of Oxygen and Aluminum Contents on the Properties of Titanium-Aluminum-Oxygen Alloys During Cyclic Straining," to be published as Boeing Document, 1970

38. G. P. Rauscher, "Effect of Oxygen on the Mechanical and Stress Corrosion Properties of Binary Titanium-Aluminum Alloys," to be published as Boeing Document, 1970

39. H. R. Smith, "A Recommended Practice for the Use of Precracked Specimens in Stress Corrosion Testing of Metallic Materials," a specification submitted to ASTM for acceptance, 1970

40. G. Hari Narayanan and T. F. Archbold, "Decomposition of the Metastable Phase in the All Beta Alloy Ti-13V-11Cr-3Al," submitted to ASM Trans. Quar. for publication, 1970

41. D. N. Fager, "Aqueous Stress Corrosion Susceptibility of Ti-8Al-1Mo-1V as Influenced by Preferred Orientation and Near Plane Strain Conditions," to be submitted to Corrosion for publication, 1970

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<u>University of Florida</u>

1. M. Pourbaix, "Research in Corrosion-Results of Recent Work," CEBELCOR's Rapports Techniques <u>109</u>, Aug 1969, pp. RT.109 (in French)

2. M. Pourbaix, "Electrochemistry of the Aqueous Corrosion in Restricted Diffusion (Pitting, Stress-Corrosion Cracking, Intergranular Corrosion, Crevice Corrosion) and Hydrogen Embrittlement," Abstract in CEBELCOR's Rapports Techniques <u>111</u>, Nov 1969, pp. RT.165/3 (in French)

3. E. D. Verink, Jr., and P. A. Parrish, "Use of Pourbaix Diagrams in Predicting Susceptibility to DeAlloying Phenomena," Corrosion <u>26</u>:5, May 1970

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6. R. L. Cusumano, "Construction of Three-Dimensional (Potential-pH-Composition) Pourbaix Diagrams for the Iron-Rich Alloys of the Binary Fe-Cr Alloy System," M.S. Thesis, Dec 70 (expected date)

7. K. D. Efird, "Correlation of the Protection Potential with Crevice Corrosion Behavior of Engineering Alloys," M.S. Thesis, Dec 1970 (expected award date)

ACKNOWLEDGMENTS

This research was supported by the Advanced Research Projects Agency of the Department of Defense, NRL Problem M04-08, and was monitored by the Naval Research Laboratory under Contract Nos. Nonr-610(09), Nonr-760(31), N00014-66-C0365, Nonr-991(15), N00014-68A-0245-0001, and N00014-68-A-0173-0003.

This series of reports has been edited by a number of capable persons. In this last report of the series we would like to gratefully acknowledge the contributions of Dr. D. E. Piper and Dr. J. A. Feeney of The Boeing Company who edited the Titanium section, Dr. R. P. Wei of Lehigh University who edited the Steel section, and Dr. R. P. M. Procter, Dr. R. D. Townsend, Dr. C. D. Statham, and Mr. A. J. De Ardo, Jr., of Carnegie-Mellon University who edited the Aluminum Alloy section.

C. ABSTRACTS OF RELATED ARTICLES ON STRESS-CORROSION CRACKING

1. T. R. Beck, N. J. Blackburn, W. H. Smyrl, and M. O. Speidel, "Stress Corrosion Cracking of Titanium Alloys: Electrochemical Kinetics, SCC Studies with Ti: 8-1-1, SCC and Polarization Curves in Molten Salts, Liquid Metal Embrittlement, and SCC Studies with Other Titanium Alloys," Quarterly Progress Report No. 14, October 1, 1969, through December 31, 1969. Contract NAS 7-489, Boeing Scientific Research Laboratories, Seattle, Washington

   Much of the work performed in the last nine months has been concerned with the evaluation of cracking behavior of titanium and aluminum in a wider variety of environments. Crack propagation in titanium alloys has been studied in mercury, molten salts, organic solvents, and aqueous environments. A great many similarities were found as to the effect of metal structure, stress, and environment conditions on crack propagation velocity. A new and somewhat different type of stress-corrosion cracking has been found to occur in Ti-Mo type alloys and preliminary data for the alloy Ti-12Mo-6Zr-5Sn (Beta III) are described. Techniques have been refined for studies of electrochemical kinetics and for observation of crack growth in single metal grains.

D. DIARY OF EVENTS

Dr. J. A. Feeney of The Boeing Company conducted a Graduate Seminar on "Phase Transformations in Titanium Alloys" at the Department of Materials Science and Engineering, University of Utah, on 10 February 1970.

Dr. D. E. Piper of The Boeing Company attended the 30th Meeting of the Structures and Materials Panel of the Advisory Group for Aerospace Research and Development (AGARD) of NATO held in Athens, Greece, on 5-10 April 1970. He presented a final report of his 1969 European and North American survey of test methods for stress-corrosion cracking. As Coordinator to the Working Group on Stress Corrosion, Dr. Piper will plan a two-day symposium on Testing Methods for Stress Corrosion to be held in April 1971 in conjunction with the 32nd Panel Meeting in London, England.

As the U.S. member, Dr. B. F. Brown of the Naval Research Laboratory attended the Working Group meeting in Penina, Algarve, Portugal, 15-16 May 1970, to help organize a conference on stress corrosion for the NATO Science Committee. The conference is to be held in Portugal, 28 March-2 April 1971.

UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Naval Research Laboratory Washington, D.C. 20390	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

ARPA COUPLING PROGRAM ON STRESS-CORROSION CRACKING
(Fourteenth Quarterly Report)

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

This report is the final quarterly report of the series.

5. AUTHOR(S) (First name, middle initial, last name)

G. Sandoz (General Editor)

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
May 1970	44	---

8a. CONTRACT OR GRANT NO. M04-08A b. PROJECT NO. c. ARPA Order 878 d.	9a. ORIGINATOR'S REPORT NUMBER(S) NRL Memorandum Report 2141 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. DISTRIBUTION STATEMENT

This document has been approved for public release and sale; its distribution is unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	Advanced Research Projects Agency, Department of Defense

13. ABSTRACT

This report contains a compilation of abstracts from journal articles, recent reports, and talks generated under the ARPA Coupling Program on Stress-Corrosion Cracking, ARPA Order 878. The abstracts are from work done at The Boeing Company, Carnegie-Mellon University, Lehigh University, and the Naval Research Laboratory. Selected abstracts of articles from outside the ARPA Program in the field of stress-corrosion cracking are also included as well as a Diary of Events section.

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Stress-corrosion cracking						
High strength steels						
Titanium alloys						
Aluminum alloys						
Electrochemistry						
Fracture mechanics						
Surface chemistry						